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Ultraviolet Induced Motion of a Fluorescent Dust Cloud in an Argon Direct Current Glow Discharge Plasma

Michael George Hvasta and Andrew Zwicker

ABSTRACT

Dusty plasmas consist of electrons, ions, neutrals and nm-μm sized particles commonly referred to as dust. In man-made plasmas this dust may represent impurities in a tokamak or plasma etching processing. In astrophysical plasmas this dust forms structures such as planetary rings and comet tails. To study dusty plasma dynamics an experiment was designed in which a 3:1 silica (<5 μm diameter) and fluorescent dust mixture was added to an argon DC glow discharge plasma and exposed to UV radiation. This fluorescent lighting technique offers an advantage over laser scattering (which only allows two-dimensional slices of the cloud to be observed) and is simpler than scanning mirror techniques or particle image velocimetry. Under typical parameters (P=150 mTorr, V_{anode}= 100 V, $V_{cathode}$= -400 V, I_{total} < 2mA) when the cloud is exposed to the UV light (100W, λ = 365 nm) the mixture fluoresces, moves ~2mm towards the light source and begins rotating in a clockwise manner (as seen from the cathode). By calibrating a UV lamp and adjusting the relative intensity of the UV with a variable transformer it was found that both translational and rotational velocities are a function of UV intensity. Additionally, it was determined that bulk cloud rotation is not seen when the dust tray is not grounded while bulk translation is. This ongoing experiment represents a novel way to control contamination in man-made plasmas and a path to a better understanding of UV-bathed plasma systems in space.

Introduction

Dusty plasmas (sometimes referred to as complex plasmas) are comprised of electrons, ions, neutrals and comparatively large particles (dust). On Earth, dusty plasmas are seen in plasma processing facilities and tokamaks where the dust is typically considered to be contamination. Therefore, it is important to learn how to control and limit the negative effects of these particles. In space, astrophysical dusty plasmas create comet tails, planetary rings and are a major component of the interstellar medium. These dusty plasmas, outside of our protective atmosphere, are bathed in ultraviolet (UV) light and must be better understood if we are to comprehend most of the visible universe [1, 2, 3]. To this end, the aim of the Dusty Plasma experiment (DPX) is to investigate the dynamics of dusty plasma systems and their interactions with UV light.

Traditionally, laboratory dusty plasmas are illuminated with a laser-sheet that reveals two-dimensional cross-sections of the cloud. In this experiment, in order to study the three-dimensional structure of the dust cloud, a fluorescent dust mixture is used that enables the entire cloud structure to become visible when exposed to UV light. Beyond uniformly illuminating the entire cloud, the experiment serendipitously provided a method of making the cone shaped dust cloud move and rotate. The following details the progress made in characterizing and explaining this motion.

Materials & Research

The majority of our research was carried out in a 13.5" long cylindrical chamber with a 6" diameter. Figure 1 depicts the six-way cross configuration that was used.

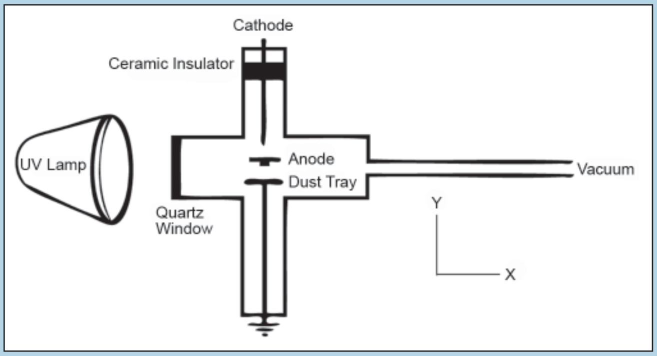


Figure 1. A schematic depicting the experimental setup.

The dust tray consisted of a 1.9" x 0.25" stainless steel disc that was screwed onto a 0.5" diameter stainless steel shaft. The electrodes in the experiment were made from 0.5" diameter stainless steel rods. All of the stainless steel shafts were installed through Wilson-seals that allowed for the adjustment of their location and orientation. The tray and the chamber were grounded.

The negatively biased cathode ($V = {}^{-}400$ Volts) was positioned parallel to the Y-axis 2.0–2.5" above the dust tray. The positively biased anode ($V = +100$ Volts) was installed parallel to the Z-axis 1.0–1.5" above the dust tray. On top of the anode, near the tip of the electrode was another 1.9" x 0.25" stainless steel disc. This geometrical setup proved useful in creating distinct cone shaped clouds as seen below in Figure 2.

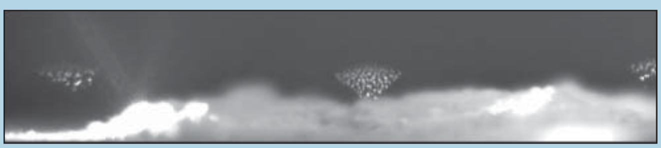


Figure 2. Three distinct dust clouds formed above the dust tray. The third cloud, on the far right, is cut-off. The diameter of the central cloud is ~ 2mm.

Typically, the dust was deposited on the dust tray after the chamber had been cleaned. The electrodes were scrubbed with acetone while the walls were washed with alcohol to prevent ruining the vacuum compatible paint used to add contrast during observation. The chamber pressure was then reduced to ~10^{-6} Torr before the volume was backfilled with 150 mTorr of argon. The experiment would begin by applying 1–3 kV to the anode to produce an electrical arc down towards the grounded dust tray that would excite the dust into the plasma.

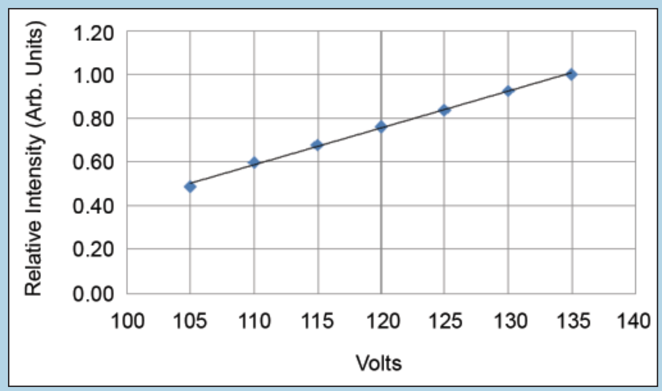
Once the dust was excited into the plasma, electron capture would allow the dust grains to obtain a negative charge. The resulting attraction between the negative particles and the anode would offset downward gravitational forces and allow the particles to float within the plasma [4, 5]. The clouds could then be exposed to UV light which would cause the dust cloud to fluoresce, translate towards the light source and begin rotating in a clockwise manner (as seen from the cathode).

Dust dynamics were captured using a CCD camera with 640 x 480 resolution at 30 fps. After filming, the camera would be rotated to face a ruler and, without touching the focus controls, its distance from a ruler would be adjusted until the etchings on the ruler were clearly in focus. Once the ruler was in focus the width and height of the frame could be determined. The width would be divided by 640 and the height would be divided by 480 to give us the dimensions of an individual pixel. A program called ImageJ was used to determine the number of pixels between two points and this information could then be converted into displacement. Since each frame represented 1/30th of a second, the average velocity between two points could be obtained by dividing the displacement by (n/30), where n is the number of frames between the two measurements.

Results and Discussion

The research consisted of two primary studies. The first was designed to investigate the relationship between dust cloud motion and UV light intensity. The second was designed to determine whether or not chamber wall outgassing was responsible for cloud movement.

The UV lamp was calibrated by connecting it to a Variac variable transformer and measuring the relative UV intensities at varying voltages with a spectrometer. Conveniently, the UV intensity's dependence on voltage was linear as seen below in Graph 1.

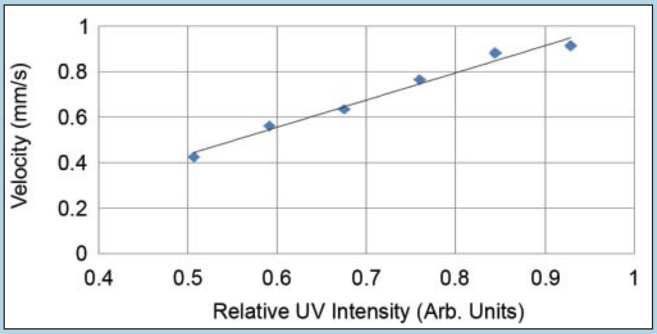


Graph 1. The UV intensity of the lamp scaled linearly with voltage.

Using the above calibration curve, the dust clouds suspended above the electrically grounded dust tray could be exposed to specific relative intensities of UV light. It was then determined that the velocity of the rotating cloud's particles at any given focal length was linearly dependent on UV intensity. Particle velocity decreased towards the center of the dust cloud and no rotation occurred when the dust tray was not grounded.

The cloud's translation towards the light tended to be more extreme as UV intensity increased and was unaffected by the floating or grounding of the dust tray.

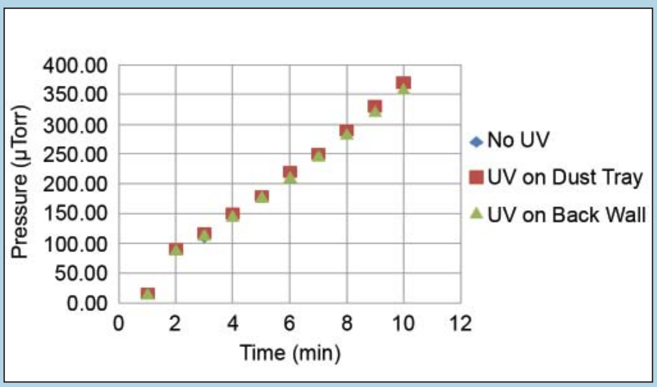
A second study was needed to ensure that the observed effects in the first study were electrical in nature and not simply due to the paint on the chamber walls out-gassing and pushing the cloud towards the light. To this end, another series of experiments was performed to see if neutral particles or some other form of out-gassing could provide a mechanism for cloud translation [6, 7].



Graph 2. The linear relationship between particle velocity within the rotating cloud and UV intensity.

When the pressure in the chamber was at 1.5 x 10^{-5} Torr the chamber was isolated from the vacuum system and the pressure was monitored. Without any outside influence the chamber would slowly leak and/or out-gas and raise the pressure. This pressure vs. time reading became the benchmark for the next portion of the experiment.

In the next step, a focused beam of UV light, with three times the intensity of the regular lamp, was aimed at the dust on the tray and then the paint on the back wall of the chamber, opposite the UV lamp. For both scenarios the pressure was monitored as a function of time. Graph 3 depicts the results showing almost no differences in pressure due to UV related out-gassing.



Graph 3. There is almost no difference in the rate of rising pressure within the chamber due to UV induced outgassing.

Another step was needed to see if heat from the UV lamp played a significant role in increasing the pressure within the chamber. The system was heated using the UV lamp in its regular position and with heating tape at 100°F on the back wall of the chamber. Prolonged UV lamp heating lasting 10 minutes provided little more than a .1 mTorr increase in pressure. The heating tape proved to be effective at increasing the pressure but on a level that was unobtainable with the UV lamp alone.

As a final test, the chamber was opened and the 3:1 dust mixture was replaced with pure silica. Upon repeating the same experiments with the UV lamp on the silica none of the same rotational or translational effects were seen.

Conclusion

The linear dependence on UV light intensity in the first study coupled with the lack of convincing evidence for out-gassing in the second study leads to the conclusion that the cause of the observed motion is due primarily to UV photoionization and its corresponding electrical effects [8].

Future microgravity work aboard NASA's 'Vomit-Comet' is scheduled for early June, 2008. Without gravity, the research group hopes to find the relationship between dust cloud movement and its proximity to the grounded dust tray.

More information about this and future work is available at www.DustyPlasma.org.

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